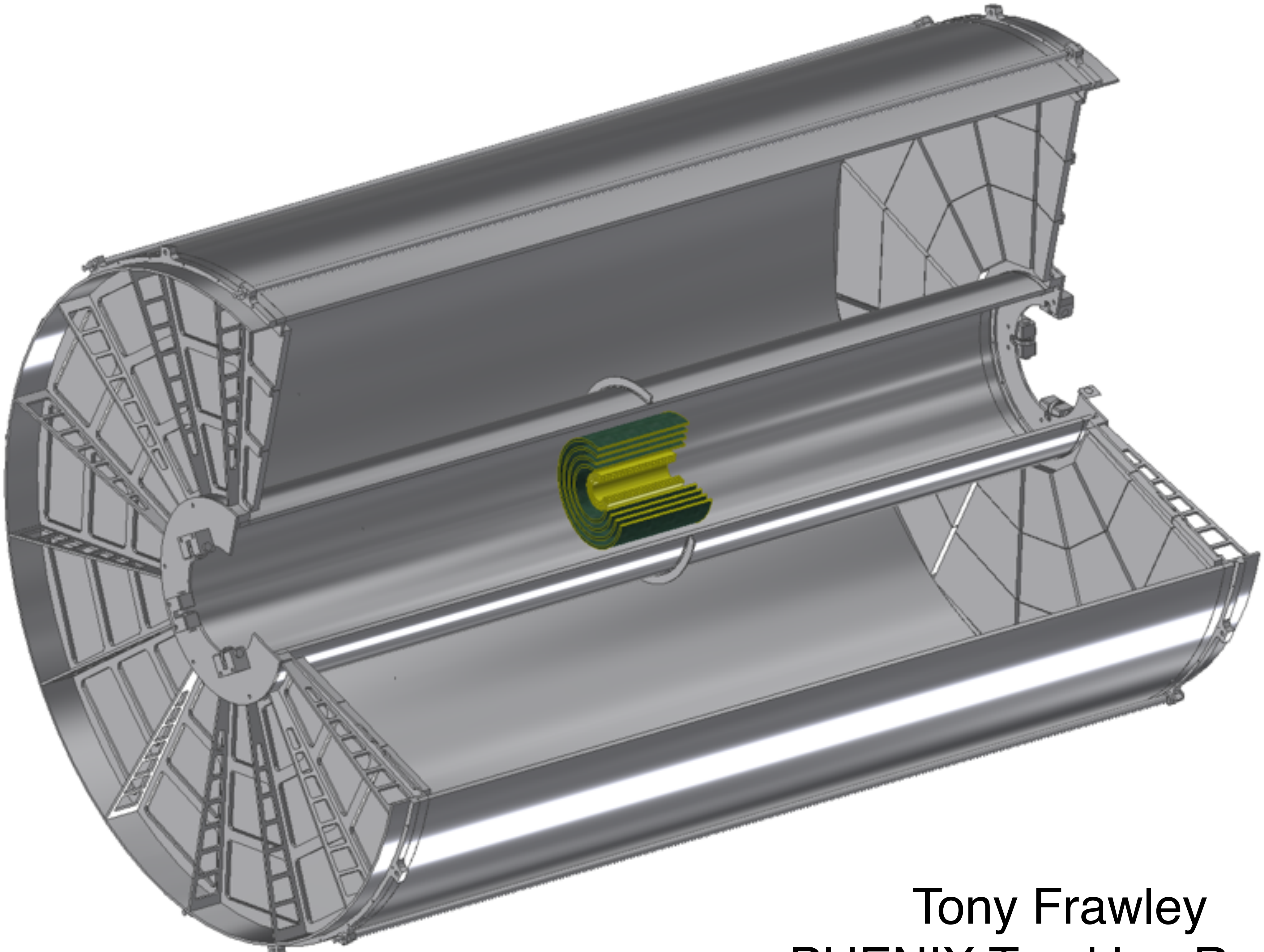
Tracker Simulations



Tony Frawley
sPHENIX Tracking Review
September 7, 2016

Goals

Physics program driven goals of tracking simulations:

Momentum resolution

- Upsilon program requires σ_{mass} for Upsilon of < 100 MeV
  - Determined by decay electron momentum resolution at 5 - 10 GeV/c
- Jet physics program requires σ_{p_T} ~ a few percent at ~ 40 GeV/c

DCA resolution

- Heavy flavor tagged jets require σ_{DCA} < 70 µm (smaller the better!)

Single track efficiency - important for multi-track measurements

- Heavy flavor tagged jets require multi-track measurements
- Upsilons require di-electron measurements

Pattern recognition

- Fake tracks in Au+Au $\longrightarrow$ background noise in jet measurements

Tracking simulations

All results shown here use a model where each tracking detector consists of uniform cylindrical tracking layers of sensitive material and uniform cylindrical layers representing inactive support material.

Silicon trackers:

- Layer of sensitive Si divided into pixels (MAPS) or strips (INTT)
- Layer of Cu to make up the total average thickness

TPC

- Layer of inactive material for inner field cage
- layer of inactive gas from 20-30 cm radius
- 60 layers of active gas divided into “voxels” of 1.5 mm x 1.7 mm
- layer of inactive material for outer field cage

Tracking active layers

Layer	Type	Radius (cm)	active thickness	total thickness (X_0)	cell pitch	cell length (in Z)
0	MAPS	2.3	50 µm	0.3%	20 µm	20 µm
1	MAPS	3.2	50 µm	0.3%	20 µm	20 µm
2	MAPS	3.9	50 µm	0.3%	20 µm	20 µm
3	Si strip	6.0	120 µm	1%	80 µm	1.2 cm
4	Si strip	8.0	120 µm	1%	80 µm	1.2 cm
5	Si strip	10.0	120 µm	1%	80 µm	1.2 cm
6	Si strip	12.0	120 µm	1%	80 µm	1.2 cm
7-67*+	TPC gas	30-80 cm	50/60 cm	1%+0.2% +1%	1.5 mm	1.7 mm

*TPC layer counts of 30 and 48 tested, no performance degradation

+TPC gas volume also includes dead area from 20-30 cm radius

MAPS pixel simulations

MAPS pixels (28 µm x 28 µm) not isolated from each other

- Electrons will be shared by multiple pixels
- This improves the position resolution

Charge sharing not yet included in the simulation

- Most hits in sims are single pixel
- Estimated effective position resolution is 20 µm / $\sqrt{12}$
- So the pixel size is set to 20 µm in simulation

Active depth of pixels is 19 µm

- For historical reasons, we use 50 µm in simulation
- But we adjust thresholds to match performance expectations from ALICE experts

TPC simulations

Electron drift and diffusion in gas

Uses measured parameters for T2K gas: Ar (95%) CF4 (3%) isobutane (2%)
We plan to swap 95% Ar to 95% Ne

- Less than 10% change in diffusion and other properties

Readout plane

Longitudinal diffusion (+ tilt) smears drift distance, preamp smears time - add in quadrature
Want charge on 3 readout pads - pad size set by transverse diffusion
Cluster 3 readout pads and 5 time bins when track crosses one “layer”

Space charge distortion:

Size of effect from simulations using formulae from Rossiger thesis (ALICE calculations)
Ratios of maximum distortion to corrected precision from:

- Actual performance in STAR, simulations in ALICE

STAR uses analytic calculation scaled by luminosity, ALICE claims better ratio
Used STAR ratio as our default - applied as offset **and** as sigma
Also studied making factor worse, got little degradation
We get small space charge distortion using two tricks:

- Operate in zone favoring lowest ion back flow (trade off against dE/dx performance)
- Put entrance of field cage at 20 cm, moves max distortion point outside tracking volume
  - 3 cm distortion at 20 cm drops to 3 mm at 30 cm (20 cm at inner field cage for ALICE)

Intermediate tracker will allow us to check distortion corrections (not taken credit for here)

Tracking software

Start with G4 hits with energy loss

- Digitize cell energy, apply threshold
- Cluster cell hits, apply threshold, estimate position uncertainties
- Clusters are input to tracker

Track:

- Hough transform to find tracks in helix parameter space
- Kalman filter to fit tracks
- Ghost rejection to reject duplicate tracks with poorer χ^2

Evaluation module to gather and crosslink diagnostic information

- Truth hits
  - With link to truth track
- Truth tracks
- Reconstructed track details
  - With link to dominant truth track
- Reconstructed clusters
  - With links to associated truth hits, truth track, reconstructed track

Performance simulations with Hijing + embedded pions

Central Hijing events (0-4 fm) +100 embedded pions each.

Embedded pions

- p_T = 0.5 - 50 GeV/c in steps of 0.5 GeV/c.
- p_T and DCA (bend plane) resolution plots
  - embedded pion tracks only
- Single track efficiency plots
  - embedded pions only, using a 4σ cut on reconstructed p_T.

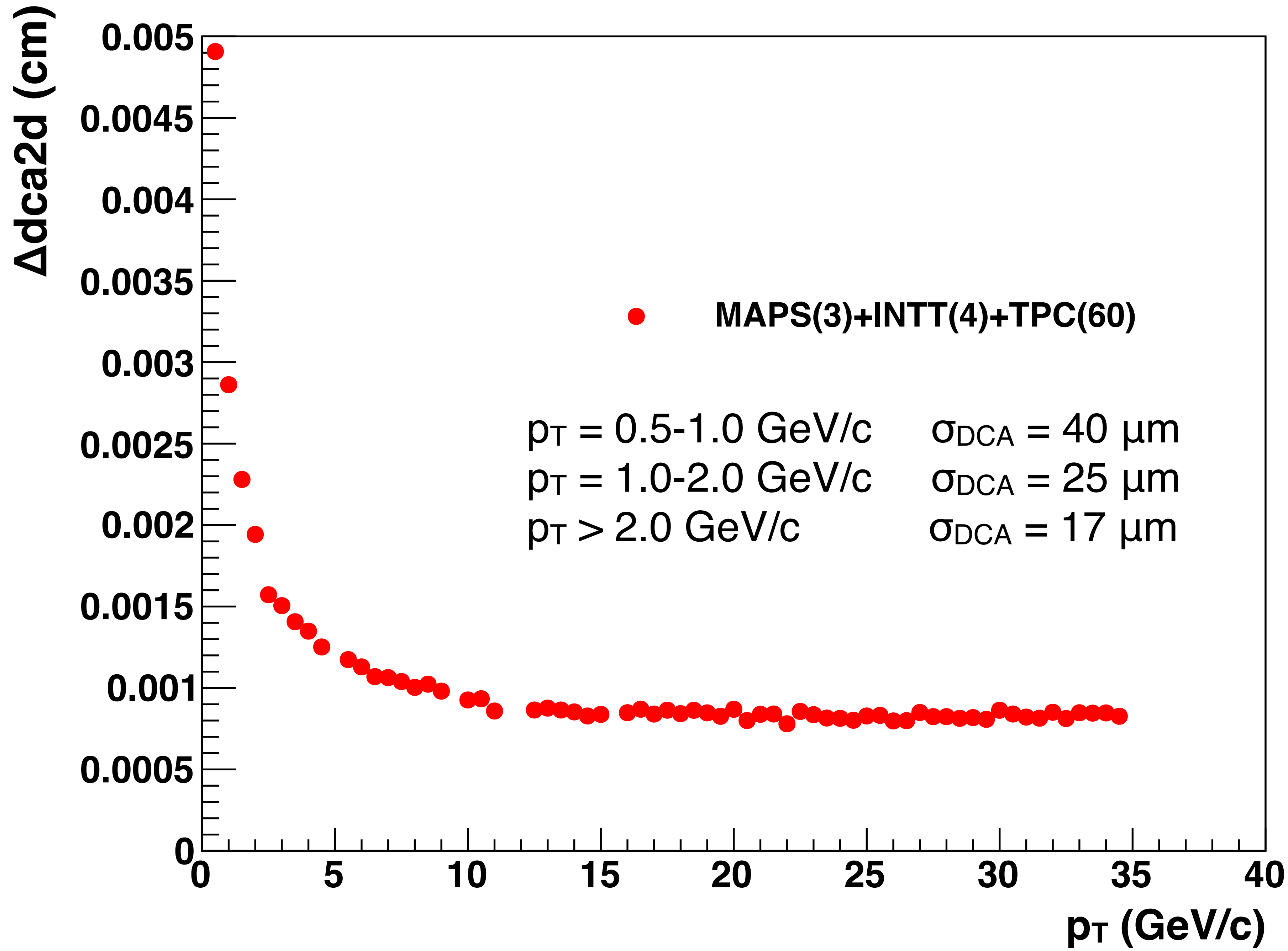
Hijing tracks

- DCA distributions and track purity plots (Hijing tracks only).
- Track purity plots (Hijing tracks only)

DCA resolution

embedded pions only
central Hijing
\+ 100 pions/event

quality < 1.5
dca2d < 1 mm
dcaZ < 1 mm

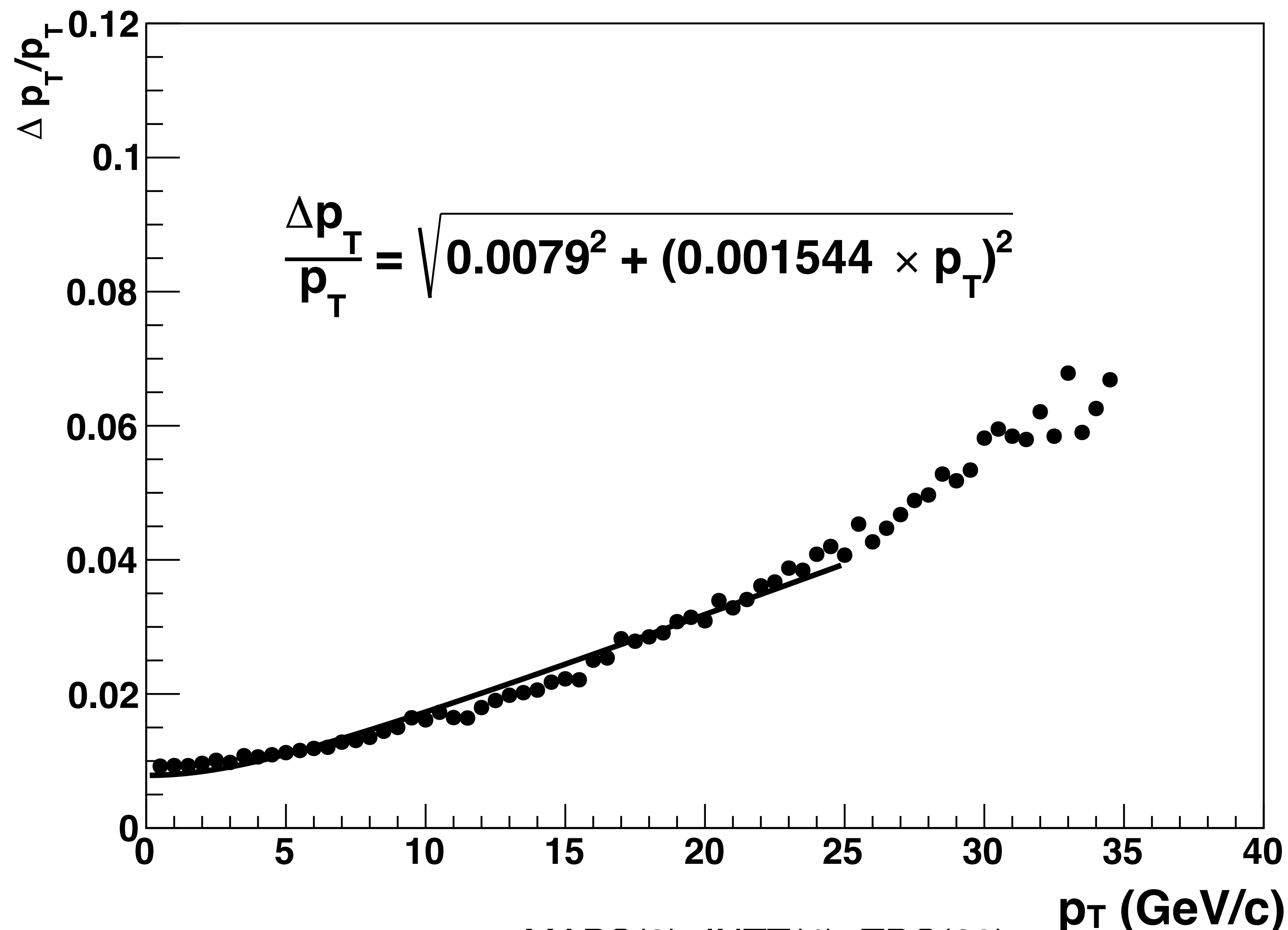


Easily exceeds sPHENIX specification of < 70 μm

Momentum resolution

embedded pions only
central Hijing
+ 100 pions/event

quality < 1.5
dca2d < 1 mm
dcaZ < 1 mm

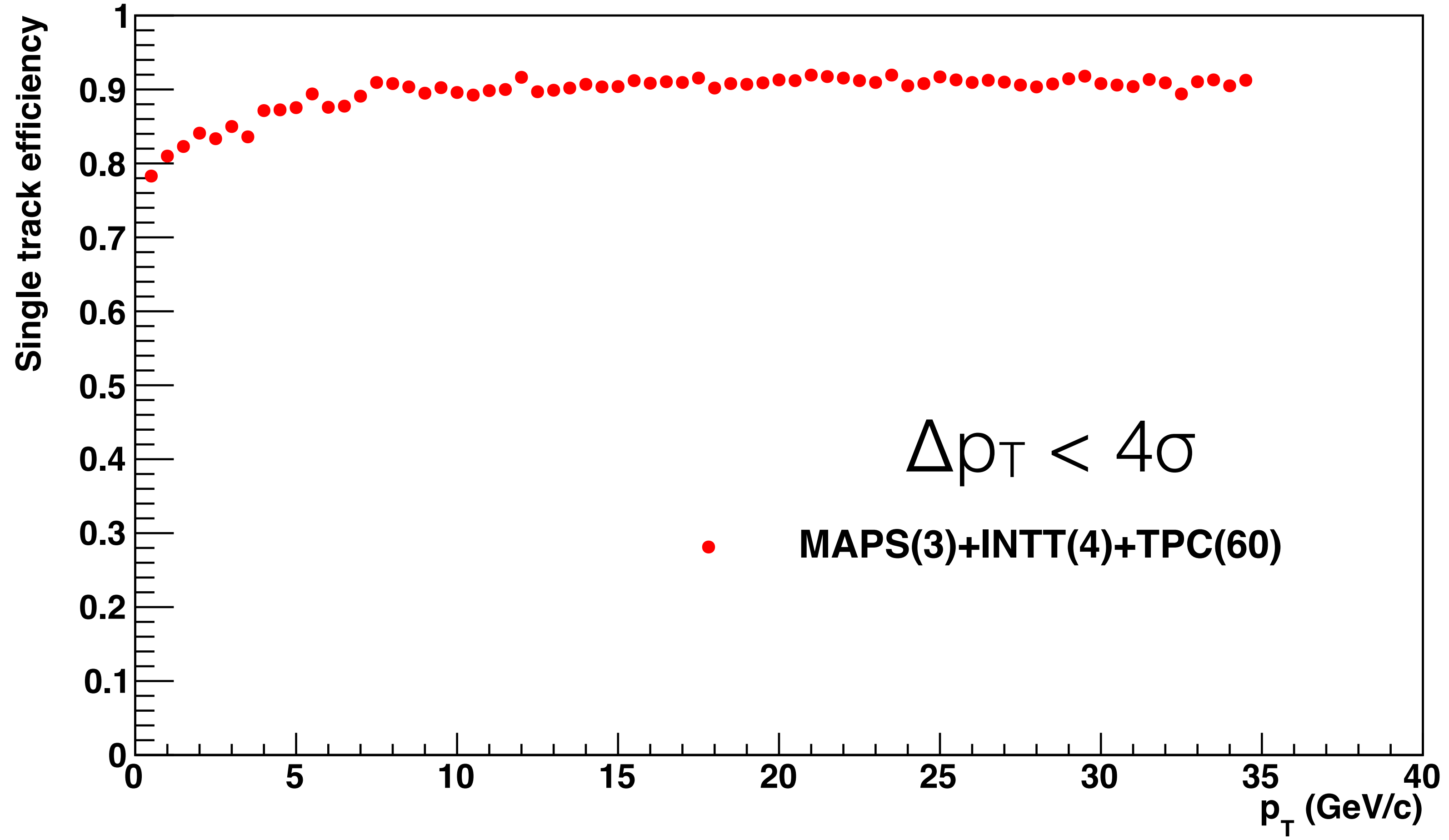


MAPS(3)+INTT(4)+TPC(60)

Single track efficiency

embedded pions only
central Hijing
\+ 100 pions/event

quality < 1.5
dca2d < 1 mm
dcaZ < 1 mm



Algorithm:
Loop over truth tracks
- Find matching reconstructed track
- Check if reconstructed $p_T < 4\sigma$ from truth

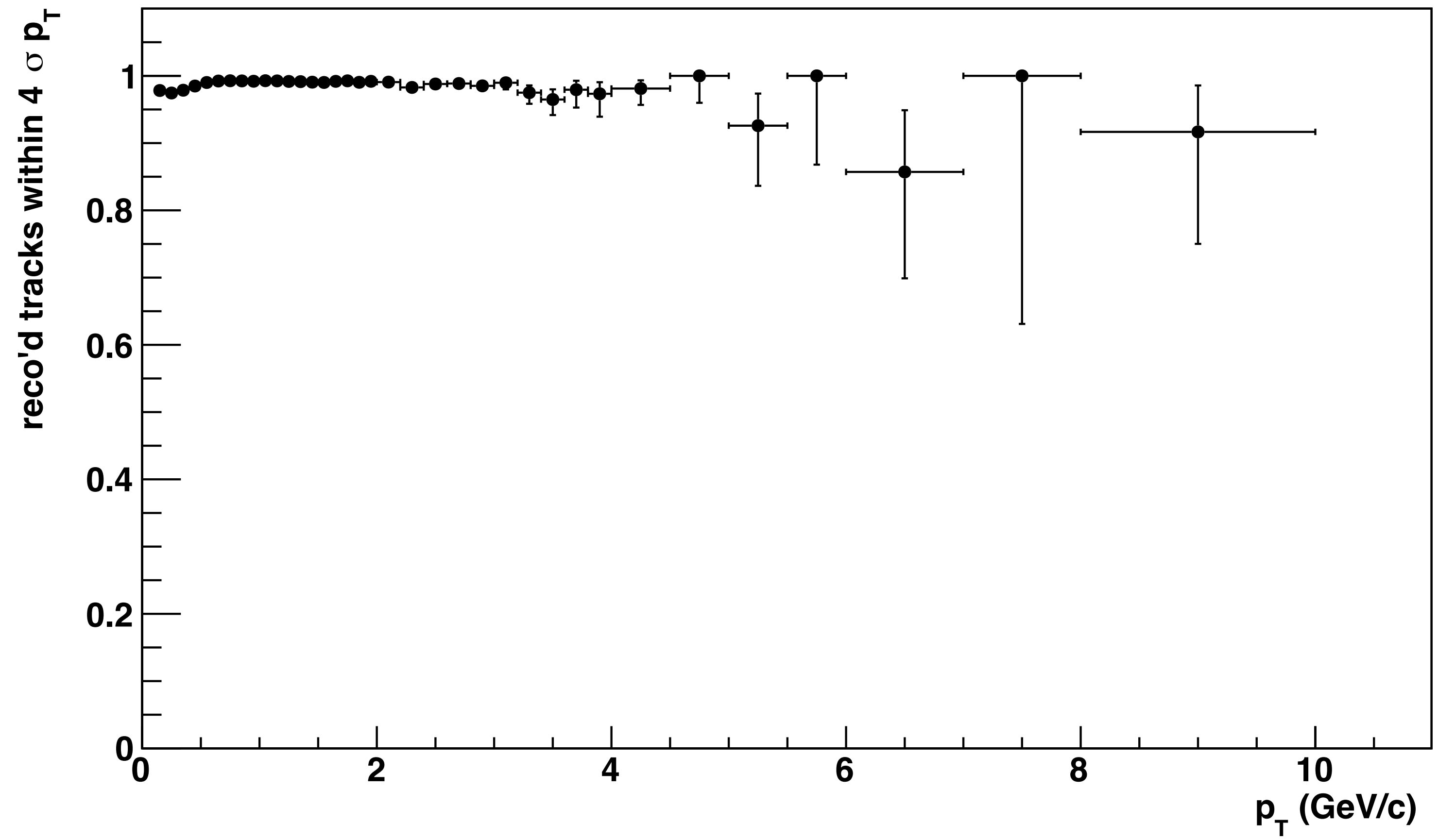
Record fraction of successful matches

Purity comparison (Hijing tracks only)

MAPS(3) + INTT(4) + TPC(60)

Fake tracks at high p_T are low p_T tracks reconstructed with incorrect momentum

Start to see evidence of a low rate of fake tracks at higher p_T



Algorithm:

Loop over reconstructed tracks

- Check reconstructed track p_T is within 4σ of truth

Record fraction of successes

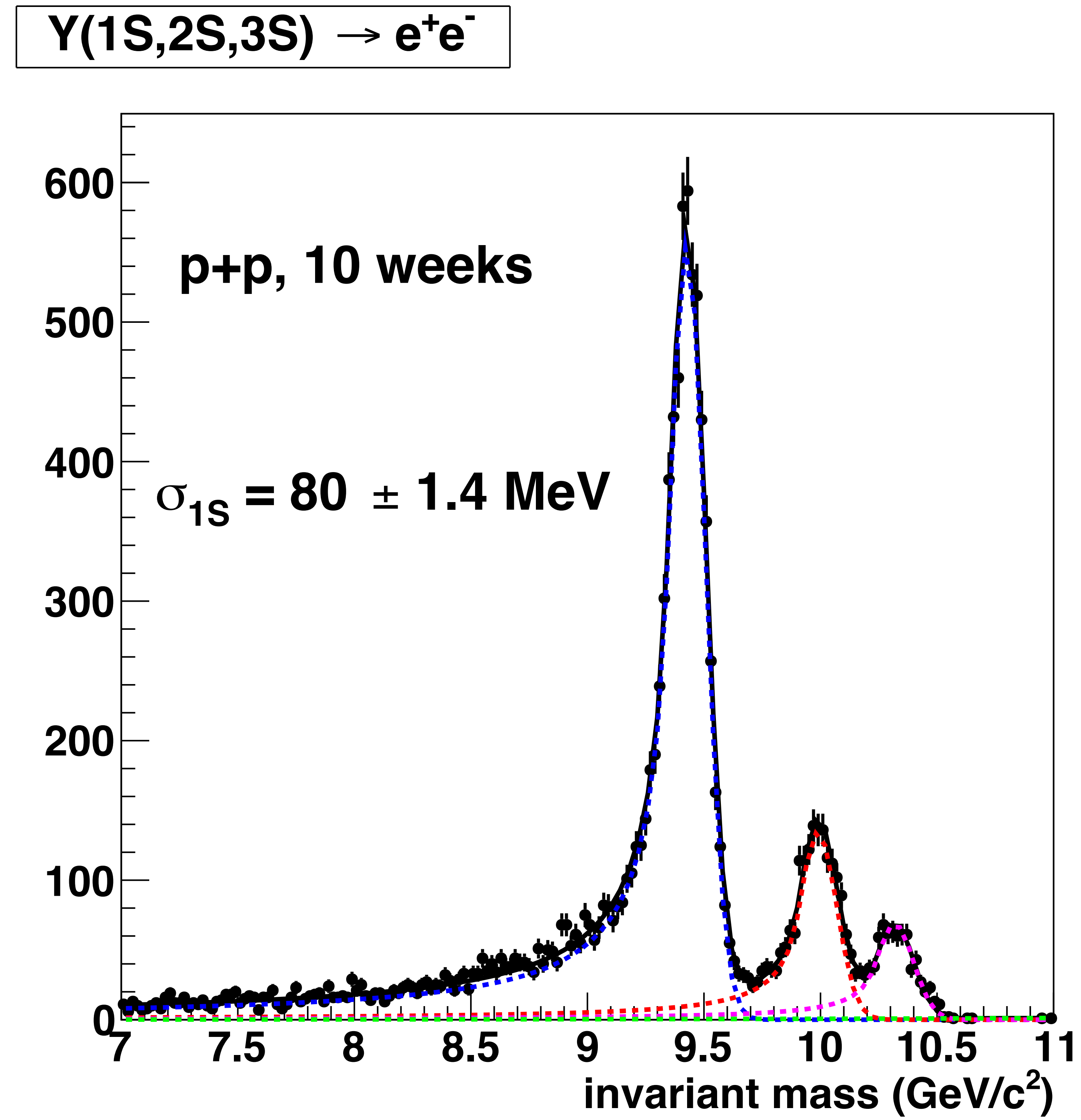
Upsilon performance

Mass resolution at Upsilon mass is 80 MeV

Easily exceeds our specification for mass resolution of 100 MeV

Yields for 10 weeks p+p:

Υ(1S) 8800
Υ(2S) 2200
Υ(3S) 1160



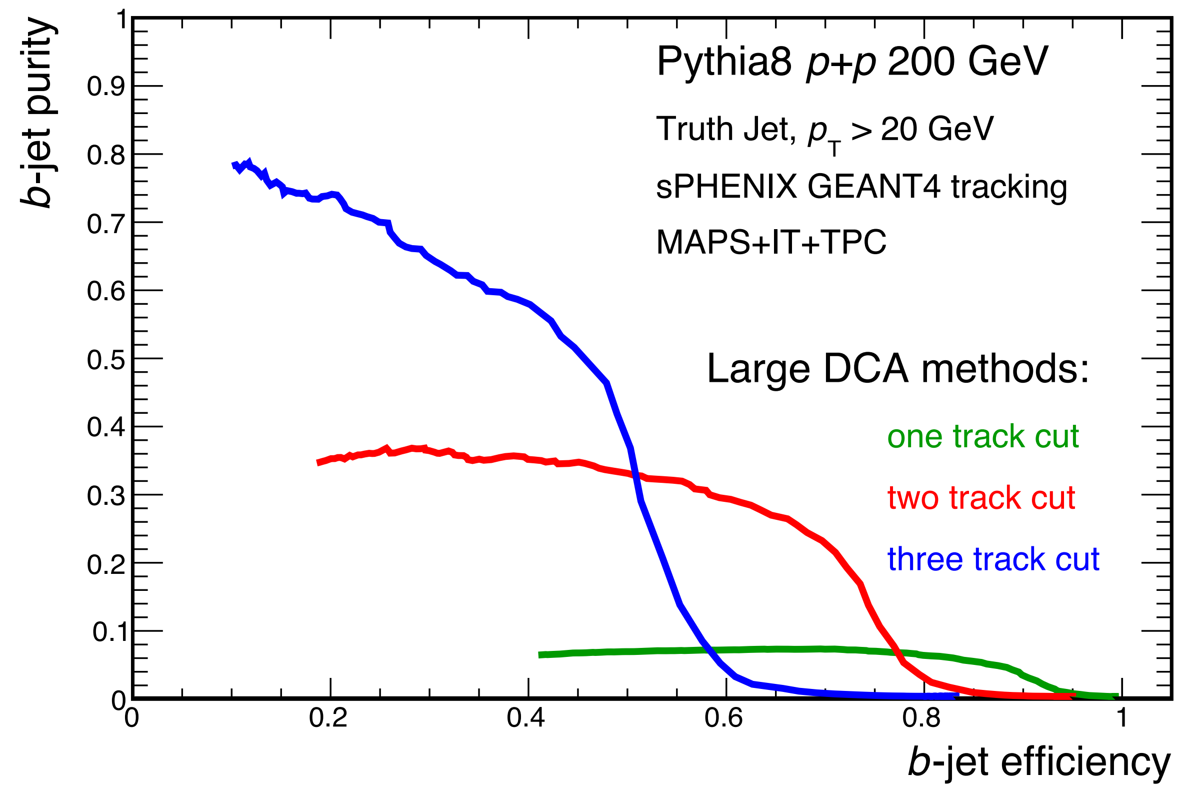
MAPS(3)+INTT(4)+TPC(60)

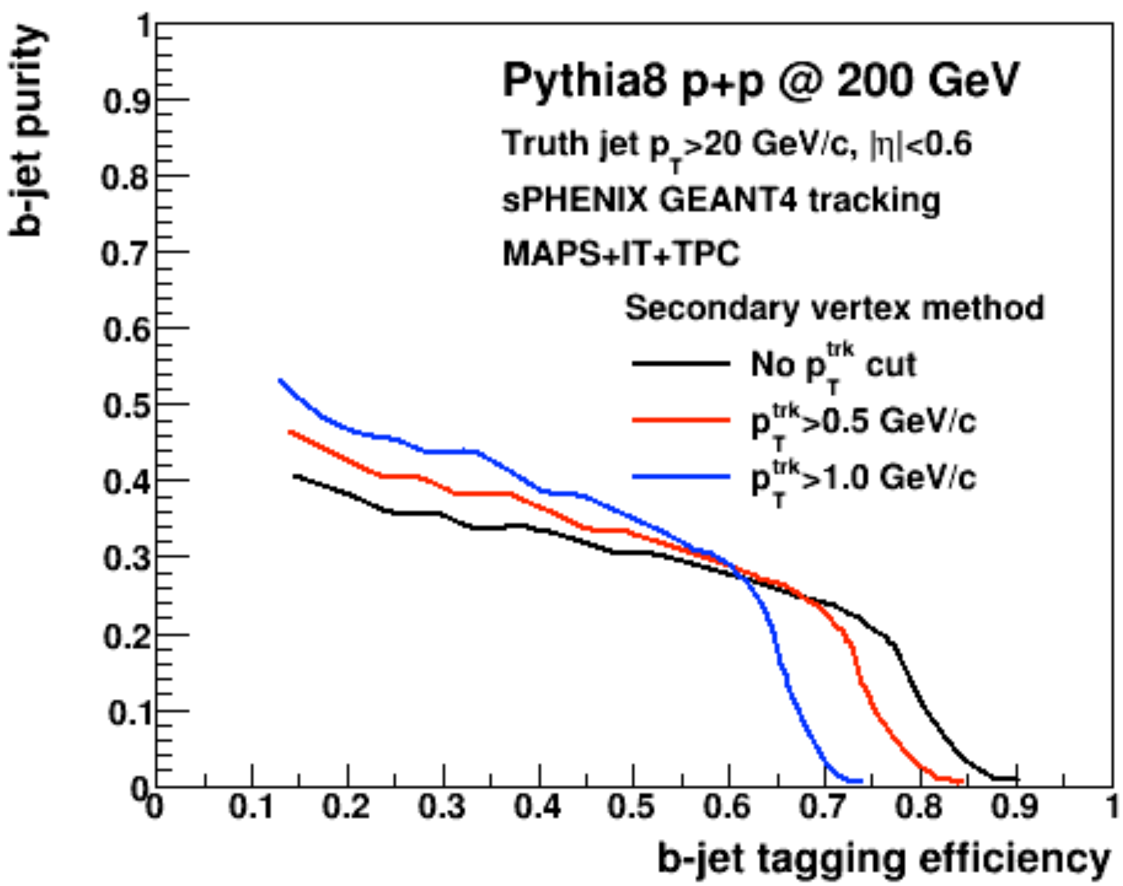
B-jet tagging performance

Plot of b-jet purity vs efficiency for large DCA track counting method

Vary DCA cut, use truth information to map out b-jet purity vs efficiency

- 30% efficiency at 70% b-jet purity





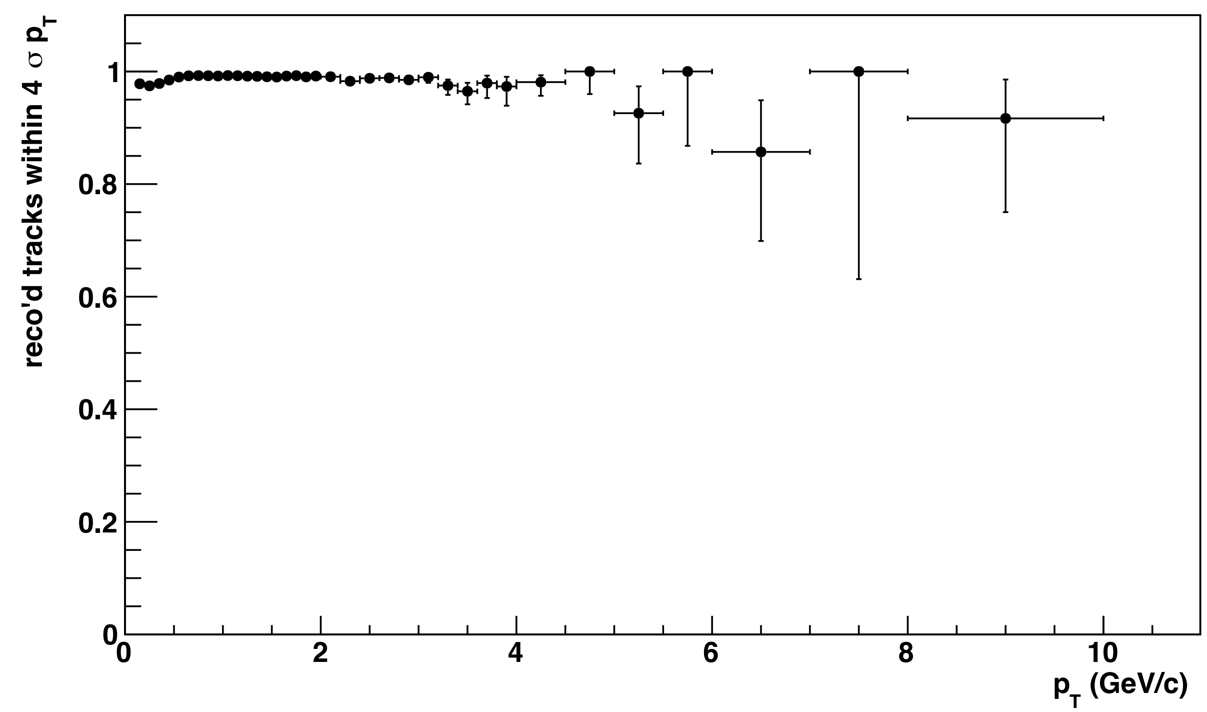
Secondary vertex finding method - uses RAVE (Reconstruction in an Abstract Versatile Environment) to find secondary vertices

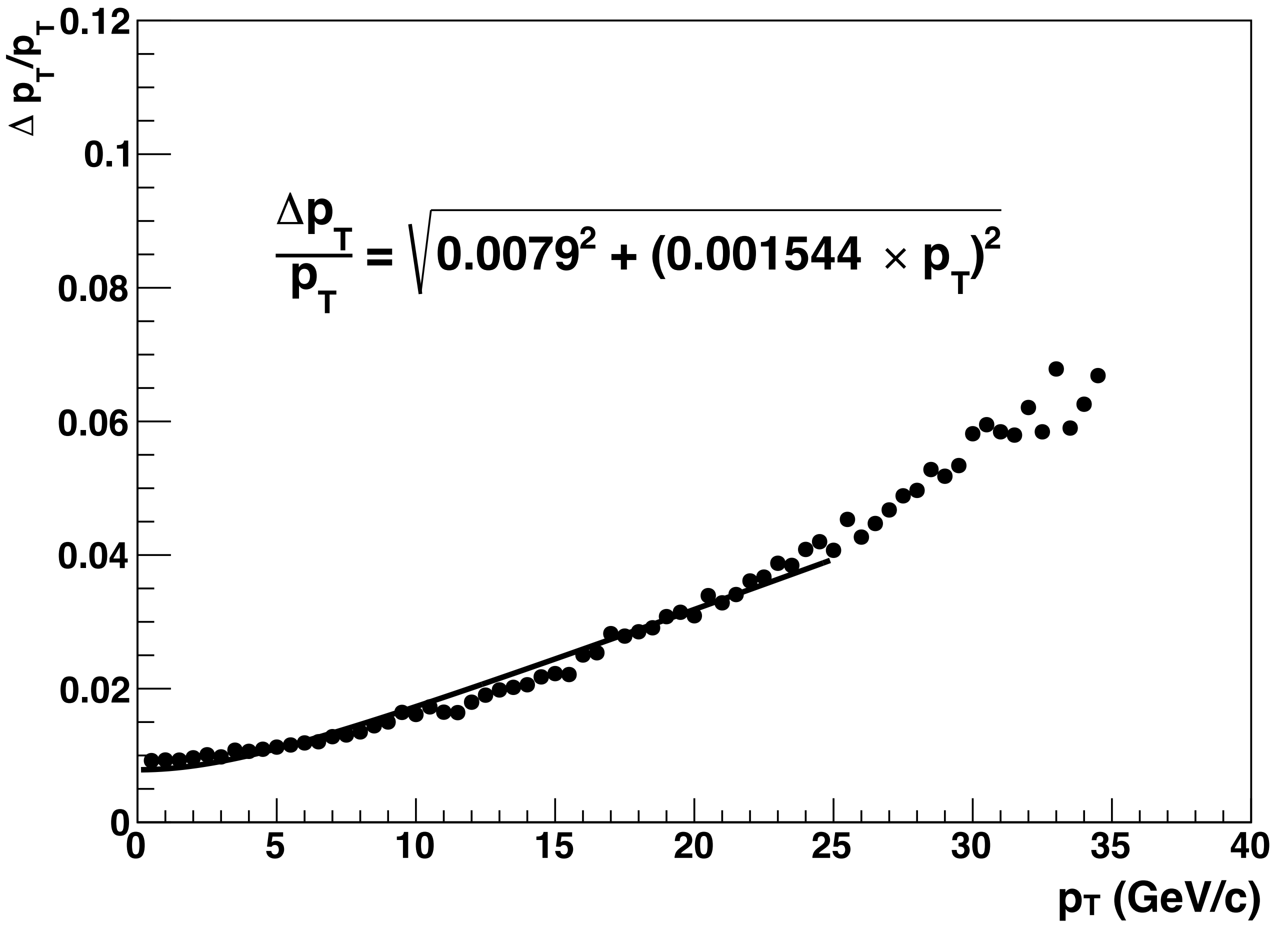
- Comparable performance to 2-track cut of large DCA method

Jet substructure performance

The ability to study jet substructure depends on

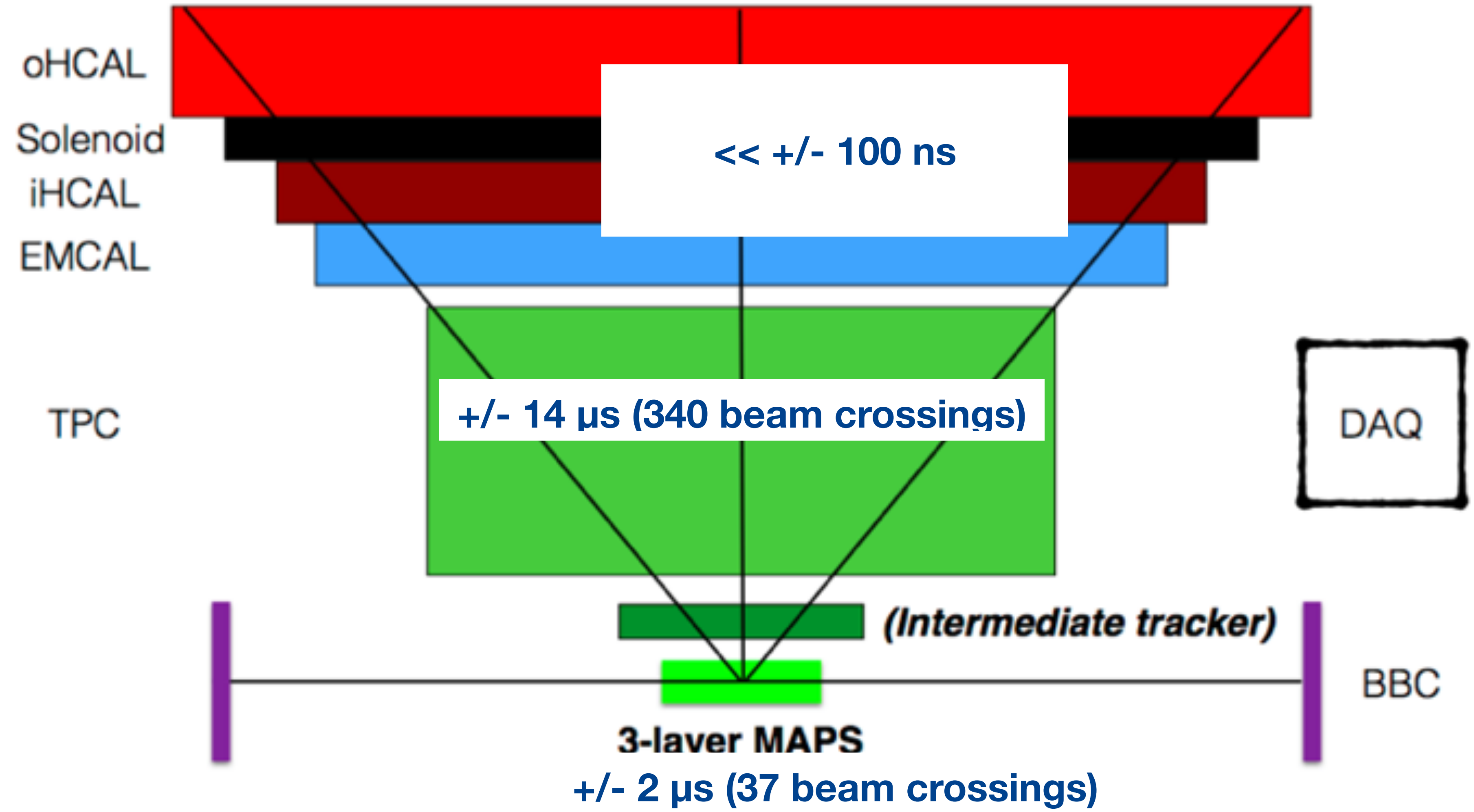
- Good pattern recognition at high multiplicity
- Acceptable momentum resolution at very high momentum





We are still working on optimizing the tracker performance in high multiplicity events

Event pileup



TPC has ~ 6 cm / μs drift velocity, integrates many beam crossings
Intermediate tracker resolves 1 beam crossing
Reject out of time track stubs in TPC and MAPS by

- Track χ^2
- Intermediate tracker confirmation

Simulations code has been modified to include out of time events
Initial results **w/o** intermediate tracker positive, studies are ongoing

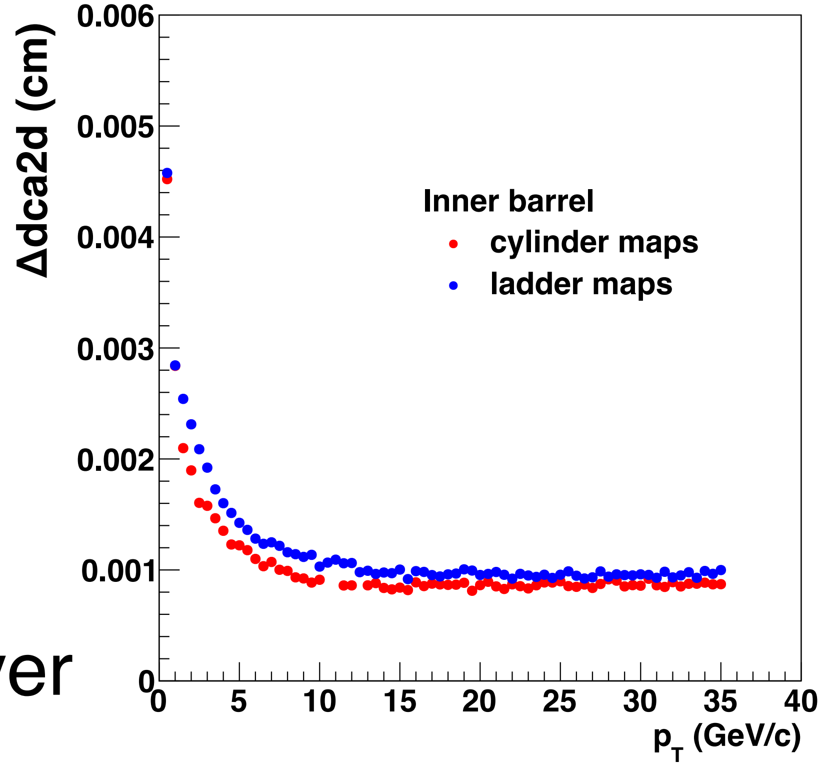
Future plans

MAPS cylinder cell model → MAPS ladders

ALICE ITS upgrade staves (inner, middle, outer) imported into sPHENIX

All associated coding completed, runs with existing tracker

- Takes only 1 hit per layer
- Differing material for each track not accounted for
- But not so bad anyway!



Future:

- More flexible tracking to handle multiple hits per layer
  - GenFit being tested
- Make material map available to tracker
- Multi-vertexing (RAVE) - implemented, being tested
- Ladder model for intermediate tracker
  - implemented for an earlier version, needs ladder geometry updated

Summary

We have performed simulations to evaluate the performance of a:

- 3 layer MAPS inner barrel
- 4 layer intermediate silicon strip tracker
- TPC outer tracker (active radius 30-78 cm)

We obtain:

- 80 MeV mass resolution for the Upsilon
- DCA resolution of < 27 μm for p_T > 1.0 GeV/c tracks
- Excellent pattern recognition in central Au+Au Hijing events
- Good momentum resolution at high p_T for jet substructure studies
- Single track efficiency of ~ 90%

The tracker performance leads to:

- Excellent mass resolution and efficiency for Upsilon measurements
- Excellent efficiency vs purity for b-tagged jets
- Low fake rate at high occupancy for jet substructure measurements

Backup